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THE IMPACTS OF POWER OUTAGES ON THE RESIDENTS OF CONTEMPORARY MULTI-STOREY APARTMENT BUILDINGS IN SUBTROPICAL ENVIRONMENTS

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Summary

With significant population growth experienced in South East Queensland over the past two decades and a high rate of growth expected to continue in coming decades, the Queensland Government is promoting urban consolidation planning policies to manage growth sustainably. Multi-residential buildings will play an important role in facilitating the increased densities which urban consolidation policies imply. However, a major flood event in January 2011 has brought to light the vulnerability of certain types of multi-residential typologies to power outages. The crisis conditions exposed how contemporary building design and construction practices, coupled with regulatory and planning issues, appear to have compromised the resilience and habitability of multi-storey residential buildings. In the greater urban area of Brisbane, Queensland, the debilitating dependence that certain types of apartment buildings have on mains electricity was highlighted by residents' experiences of the Brisbane River flood disaster, before, during and after the event. This research examined high density residential buildings in West End, Brisbane, an inner city suburb which was severely affected by the flood and is earmarked for significant urban densification under the Brisbane City Plan. Medium-to-high-density residential buildings in the suburb were mapped in flooded and non-flooded locations and a database containing information about the buildings was created. Parameters included date of construction, number of storeys, systems of access and circulation, and potential for access to natural light and ventilation for habitable areas. A series of semi-structured interviews were conducted with residents involved in the owners' management committees of several buildings to verify information the mapping could not provide. The interviews identified a number of critical systems failures due to power outage which had a significant impact on residents' wellbeing, comfort and safety. Building services such as lifts, running water, fire alarms, security systems and air-conditioning ceased to operate when power was disconnected to neighbourhoods and buildings in anticipation of rising flood waters. Lack of access to buildings and dwellings, lack of safety, lack of building security, and lack of thermal comfort affected many residents whether or not their buildings were actually subjected to inundation, with some buildings rendered uninhabitable for a prolonged period. The extent of the impact on residents was dramatically influenced by the scale and type of building inhabited, with those dwelling in buildings under a 25m height limit, with a single lift, found to be most affected. The energy-dependency and strong trend of increasing power demands of high-rise buildings is well-documented. Extended electricity outages such as the one brought about by the 2011 flood in Queensland are likely to happen more frequently than the 50-year average of the flood event itself. Electricity blackouts can result from a number of man-made or natural causes, including shortages caused by demand exceeding supply. This paper highlights the vulnerability of energy-dependent buildings to power outages and investigates options for energy security for occupants of multi-storey buildings and

makes recommendations to increase resilience and general liveability in multi-residential buildings in the subtropics through design modifications.

Keywords: multi-residential buildings, electrical systems, energy security, mobility, natural ventilation, subtropical, thermal comfort.

1. Introduction

With significant population growth experienced in South East Queensland over the past two decades and a high rate of growth expected to continue in coming decades, the Queensland Government (2009) is promoting urban consolidation planning policies to manage growth sustainably. Multi-residential buildings will play an important role in facilitating the increased densities which urban consolidation policies imply. However, a major flood event in the Brisbane River, January 2011, heavily impacted many river-side suburbs and the catastrophe has highlighted the debilitating dependence that certain types of multi-residential typologies have on mains electricity. Many multi-storey buildings were inundated and residents experienced major disruptions to 'normal' routines for several weeks. Other apartment buildings that were not directly affected by floodwater also experienced several days without power and their occupants' activities were affected temporarily. The purpose of this paper is to present the results of research undertaken in the West End peninsula which draws attention to the vulnerability of apartment buildings to power outages, and discusses factors which may exacerbate the lack of energy security of these types of buildings.

1.1 Energy dependency of high-rise buildings

The energy dependency of high-rise buildings has been well documented by Oldfield (2009), Lam (2000) and Wan (2003). Oldfield (2009) identifies the post-WW2 technological developments of the elevator, air conditioning systems and glass curtain wall facades that have been largely responsible for energy demand and energy dependency in tall buildings. Wan (2003) highlights the increase of household appliances and climate control devices as strong contributors to buildings' energy demands. In both developed and developing countries, household air-conditioners are increasingly contributing to urban electricity consumption and account for a high percentage (in the order of 40%) of peak electricity load in summer (UN Habitat, 2008). These international trends are mirrored in Australia. The 19% rise in electricity use from 2001 to 2007 can be attributed to larger home sizes, more appliances and IT equipment in homes and increased use of space heaters and coolers (ABS, 2010). A report by Engineer's Australia (2010) notes that the average Queensland household electricity bill has nearly doubled over the last decade, and while electricity demand grew twice as fast as the national average, the peak electricity demand has grown even faster. Significantly, the rates of household ownership of air-conditioning units increased from 25% to 65% between 2000 and 2008 (Pricewaterhouse Coopers, 2008).

Despite the emerging trend for "environmentally conscious" buildings that have a clear focus on sustainability and energy efficiency, the literature does not suggest that removal of all electrical systems is an option: it is implied that electricity and its subsequent services will continue to play a major role in the operation of multi-storey buildings, and the strong trend of accommodating expanding populations in multi-storey buildings will continue (MGI, 2009).

1.2 Electricity Shortages

The circumstances in Brisbane during the flood crisis of 2011, where authorities were compelled to disconnect power to flood-affected suburbs, mimicked the effects of an electricity shortage. An electricity 'blackout' is caused when demand exceeds supply, however electricity shortages are a relatively new phenomenon. Meier (2006) describes various man-made and natural phenomena which have resulted in shortages including heat waves causing high demand, droughts causing inadequate water supply for power plants, safety concerns causing plants to shut down. Extreme weather events causing electricity shortages are likely to increase in frequency and intensity (IPCC, 2007) yet community expectations for reliable



electricity supply are also rising. The recent flood in Brisbane presented an unfortunate but timely case study scenario to understand the impacts of prolonged electricity outages on the occupants of multi-storey apartment buildings.

Presumably, the existing buildings were designed and constructed in compliance with building codes and local planning codes, yet, as a result of loss of electrical energy the occupants faced particular problems during the flood event including compromised vertical access and mobility issues. In the aftermath of the flood, these problems continued for months in buildings whose electrical services and equipment sustained flood damage. The goal for this research is to investigate the resilience of apartment buildings to the impacts of power outages, and the extent to which design and compliance with regulatory issues affect or compromise the ability of buildings to maintain functionality, or to recover quickly, in the event of loss of electrical power as a result of natural disasters or other causes.

2. Research Design

The inner urban area of West End (taking in South Brisbane and Highgate Hill) was selected as a case study on the basis that it is representative of urban change across Australian cities where planning policy is aimed at urban consolidation primarily focused on sustainable values. It is ear-marked for significant population growth under the *South Brisbane Riverside Neighbourhood Plan* (Brisbane City Council, 2011) where industrial land is being redeveloped into a series of urban 'precincts'. As well as several long-established apartment buildings being situated in the suburb, numerous multi-residential buildings have been constructed in river-side locations over the past decade, as the flood-risk to these properties was deemed to be low. Using a qualitative approach in several phases, data was collected on a number of apartment buildings and combined with information gained from semi-structured interviews with building residents.

Buildings selected for a structured observational study were limited to multi-storey apartment buildings displaying systems that were considered important for electricity security such as lift cores, or HVAC plant. Figure 1 below shows the location of seventeen buildings which vary in their layouts, physical form, heights, location and date of construction. Circulation type and physical form were considered important to describe the potential for natural light and ventilation. Table 1 describes the buildings in terms of these parameters. Nine of the buildings examined were located in areas that flooded. In order to gain an understanding of people's actual experiences from a well-informed perspective, residents who were involved in owners' management committees were targeted through a local community organization and invited to participate in a series of semi-structured interviews. Six participants from four buildings were interviewed. The focus of open-ended interview questions was on which services were considered to be most critical for their building's functional operations, and which services had the largest impact on living conditions in their apartment, and on their quality of life within the building.

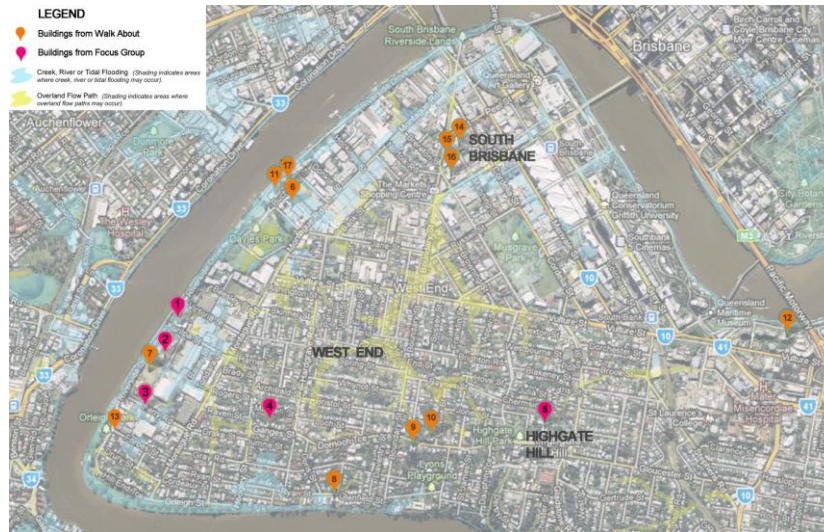


Figure 1 Location of selected multi-storey apartment buildings on the West End peninsula in Brisbane. Image adapted from: Google Maps and Near Map January 2011

	Date	Height (Storeys above ground)	No of dwellings	Circulation type (Sherwood, 1978, 2002)	Physical form (Sherwood, 1978, 2002)	Parking (levels)	Flood zone
1	2002	6	54 apartments + 5 townhouses	Gallery access	Courtyard	U/ground (1)	Yes
2	2007	6	76 apartments + 7 townhouses	Double loaded corridor	Slab	U/ground (2)	Yes
3	2009	7	34 apartments	Point access	Tower	U/ground (2)	Yes
4	1970	6	24 apartments	Point access	Tower	At grade (1)	No
5	1960	18+ 8	98 apartments + 49 apartments	Point access + Gallery access	Tower + Slab	Abv/grnd (4) At grade (1)	No No
6	2011	10	84 apartments + 5 townhouses	Gallery access	2 x Slabs	U/ground (2)	Yes
7	2011 *	8	77 + 91 apartments	Double loaded corridor	2 x Slabs	U/ground (2)	Yes
8	1985	7	14 apartments	Point access	Tower	U/ground (1)	Yes
9	1981	13	49 apartments	Point access	Tower	U/ground (2)	No
10	1982	7	45 apartments	Point access	2 x Towers	Abv/grnd (2)	No
11	2009	6	52 apartments	Point access	2 x Towers	U/ground (2)	Yes
12	1987	14	42 apartments	Point access	Slab	U/ground (2)	Yes
13	2011 *	8	297 apartments	Double loaded corridor	3 x Slab	U/ground (2)	No
14	2011	7	85 apartments	Point access	Perimeter Block (2)	U/ground	No
15	2007	6	Approx 48 apartments	Point access	Perimeter Block (3)	U/ground	No
16	2005	5	22 apartments	Point access	Perimeter Block	At grade (1) U/ground (1)	No
17	2004	7	65 apartments + 5 townhouses	Double loaded corridor	Slab	U/ground (2)	Yes

*Substantially complete but unoccupied during Jan 2011.

3. Overview of findings

The data in Table 1 reflects economic and regulatory trends in property development in the Brisbane market over recent decades. Only three of the buildings were taller than eight storeys in height: one completed in 1960, and three constructed during the 1980s building boom. Few, if any, apartment buildings over three storeys were constructed in the area in the 1990s. The model adopted by developers in recent years has tended overwhelmingly to be below nine storeys high and located in proximity to the river in the urban renewal area, though allowable buildings heights vary from four to 30 storeys depending on the site area, street frontage and the precinct (BCC, 2011). Underground parking garages are also common to this model, though not specifically mandated by the planning code. Our research found that ducted air-conditioning is present in all the buildings that were constructed since 2000. None of the pre-2000 buildings have ducted air-conditioning though several individual apartments have split-systems installed. Only three buildings do not have centralized fire sprinklers. All but three buildings have electronic building security, including intercom entry systems. All have pumps for draining basement sumps. All have electric motors for a variety of purposes.

In all cases, immobilisation of the lift had the greatest impact on residents during and after the flood. In the short term, residents of most multi-storey buildings were inconvenienced once authorities disconnected electricity to the entire area. Though power was eventually restored several days later, elevators remained out of action longer in the buildings which were inundated because lift cars, motors and control systems located in flooded basements sustained devastating damage. The buildings' fire stairs became the primary mode of vertical circulation, but were ill-designed for both evacuation (of people carrying chattels) and regular use, with poor or no artificial lighting, natural lighting or natural ventilation. Elderly and disabled individuals experienced difficulties during evacuation procedures. Some were unable to return to their homes for several weeks. Residents felt that the loss of the lifts during the 'recovery' phase would not have felt so acute if the alternative was not so inhospitable. Lack of lighting generally presented problems within individual apartments (such as bathrooms) but most of the buildings studied lacked natural light to shared corridors and stairwells. Light wells in some buildings provided daylight to corridors but not to stairwells. This was perceived by residents as a personal security risk.

Loss of fire safety systems (including alarms, booster pumps, smoke detectors and sprinklers) presented a major safety risk. Back-up power for fire sprinkler systems failed when inundated by flood waters or due to faulty fuses, creating dangerous environments for residents. Fire alarms are designed so that only Emergency Services personnel are able to switch them off. Due to the high demand and other priorities for these Services during and after the floods, many alarms sounded for days on end, heavily impacting the psychological wellbeing of residents who either chose to stay in West End during the crisis, or did not need to evacuate. In the months following the crisis, residents faced a higher risk in buildings which lacked the benefit of functioning fire safety systems.

Basement levels were inaccessible due to loss of ventilation equipment and excessive build-up of heat and fumes. Air-conditioning exhaust fans for some apartments were also located in the basement. Loss of air-conditioning systems was unpleasant for the residents in terms of air quality and thermal comfort. Interviewees commented that if their apartments were cross-ventilated this issue would have been effectively mitigated. Cross-ventilation was not an issue in the older buildings in the study whose apartments had access to at least two external faces. Four of the buildings constructed between 2004 and 2011 utilise the double-loaded corridor circulation model which disallows cross-ventilation in most circumstances. In one single-loaded 'gallery access' building the gallery corridor was enclosed in non-openable glazing thus rendering obsolete any potential cross-ventilation advantage to apartments. Some apartments are fitted with automated retractable external sun shading systems. However, without manual override for operation these devices were rendered useless, leaving apartments without protection from summer sun penetration and further exacerbating poor indoor conditions.

A problem that is quite specific to modern apartments is the electronic security system comprising important security elements such as automatic roller shutters to basement parking garages and electronic locks on main entrances which are usually linked to an intercom system. Water-damaged control boards rendered the systems inoperable, and basements and pedestrian entrances were effectively unsecured. Being unable to visually monitor entrances had various negative practical and psychological impacts on residents already upset by the flood event. During the lengthy rehabilitation period after the flood, residents were not able to use intercom or CCTV. Having to manually open the main door for visitors often entailed a long walk through the complex from their home to the shared entry through unlit corridors and stairwells. Residents and visitors also felt the loss of individual flexibility in coming and going. In at least one building with a sophisticated keyless locking system, residents instigated a curfew after which entrances were locked with chains.

Pumps for boosting water pressure for potable water supply to upper level apartments for drinking, bathing and clothes washing were affected by power outage as were sewage pumps and swimming pool pumps. Submerged pumps to drain basement sumps were of great concern. While the pumps themselves are designed to be submerged, the electronic control mechanisms are not. The basement sumps in at least one of the buildings were critical to the building's normal operation as the basement is below the water table and requires constant pumping to keep it free of water. The loss of sumps in flooded buildings prolonged the process of emptying the basement areas of flood-water and hampered the recovery of many other systems.

Multi-storey residential buildings are unlike other residential structures in that mobility, water supply, refuse management and indoor environment quality are intrinsically linked to the uninterrupted supply of electricity. The electrical systems described above fall into two main categories; those that impact the resident's activities and those that impact the resident's safety. A building's lift predominantly impacts a resident's activities, while a building's fire safety system impacts a resident's safety without impeding their daily activities. Ventilation, pumping and security systems impact both the residents' activities and safety to varying degrees. Climate-responsiveness of the dwelling, and the link to thermal comfort and to household budget emerged as an area of heightened interest to residents after the experience of prolonged power outage. The research has shown that the more energy-dependent buildings are, the more vulnerable they are to failure during power outages. In some cases compliance with regulatory issues through deemed-to-comply solutions has seen a greater dependency on electricity. In other cases, such as keyless locking, adoption of new technologies has added to the challenges of power outages.

4. Discussion

The buildings less than nine storeys high in this study were particularly vulnerable to power outages. There is no regulatory requirement for back-up power supply or an emergency lift or stair pressurisation for multi-residential buildings which have an effective height of 25m to the highest habitable floor (ABCB, 2011). Developers can avoid the greater capital costs involved in more stringent fire safety measures by not exceeding this height threshold. The post-2000 buildings in the study also demonstrate space-efficient circulation models coupled with low floor area-to-external wall area ratios, strategies favoured by developers for cost and profitability reasons. These approaches compromise access to natural ventilation and daylight while 'point access' towers from earlier decades achieved spatial efficiency in circulation, but had higher external wall area ratios because the emphasis for achieving thermal comfort was on window and door openings, orientation and appropriate external shading, rather than solely relying on air-conditioning. Designs that oblige people to use air-conditioning for indoor thermal comfort in the subtropics are not only implicated in unnecessarily high demand for electricity, but also expose occupants to power-outages and to increasing housing costs as the retail cost of electricity rises sharply. Energy costs for thermal comfort are avoidable through design, but inescapable when prohibited by design. Maintenance of expensive electronic building systems is also a long-term cost burden on the building owners. All of the energy-dependent systems which were disabled and damaged by inundation in January 2011 are high capital-cost items that are expensive to replace or to retrofit for improved resilience. In one case study building, the cost of

replacing lift motors and controls in the vulnerable basement was over \$40,000 while the cost of relocating equipment to the top of the existing shaft was six times more expensive and not able to be afforded by the Body Corporate. Further, apartment dwellers face very real difficulties in obtaining insurance to cover most risks in multi-storey buildings. Anecdotally, residents claimed that few insurance companies offer insurance for strata title buildings and flood cover had proven impossible to obtain.

Naturally, the Queensland Government responded to the flood crisis by calling for a review of existing regulations to improve the resilience of electrical equipment during floods through various physical and technical means (Queensland Government, 2011). However, an important approach to reducing vulnerability to power outages must be to reduce energy dependency by reducing energy demand through alternative design solutions which not only require less energy, but also support behavior to use less energy. For example, fire-isolated passageways, ramps and stairways of fire-resisting construction generally serve emergency evacuation procedures well, but are not suitable for everyday use. Stairways in multi-storey buildings can serve the multiple purposes of means of escape, legitimate means of circulation, and generators of light and air simultaneously within current regulatory requirements. This approach requires collaboration and motivation on the part of developers, regulators and service providers (designers and builders). Designed well, such a model can not only achieve developers' objectives of yield, but can also encourage more use of stairs for access.

Energy security is a priority for 'high risk' structures like hospitals. Though not considered 'high risk' the multi-storey apartment housing archetype is inherently energy dependent, and providing greater energy security may also be a valid matter for consideration. There is already a large body of research relating to the energy consumption of multi-residential buildings and the potential for both grid-connected and stand-alone renewable energy generation, distribution and storage (Dalton 2009, Hadjipaschalis et al 2009). Electricity generation on a residential building scale is complicated and expensive either for logistical, technical or environmental reasons. It is also evident that energy storage on a multi-residential building scale is largely untested and many of the technologies involved such as batteries are hazardous and difficult to manage in a residential environment. Though battery technology is one of the most rapidly developing methods of energy storage due to increased demand for more powerful and more portable electronic devices such as computers and phones, as well as the rapid growth of the electric and hybrid car industries, they are inherently reliant on electricity for their charge which means they would realistically be able to support only hours of continued operation after loss of power and are currently not suitable to provide electricity security to residential buildings.

5. Conclusion

The January 2011 flood disaster in Brisbane has brought the sustainability of contemporary multi-storey residential building designs into sharp focus. This study identified how the loss of electrical systems residential buildings in a subtropical environment impacted resident's lifestyles and uncovered multiple overlapping factors which influence the resilience of energy-dependent buildings.

Building services such as lifts, pumps, running water, fire alarms, security systems and air conditioning ceased to operate when authorities disconnected power to flood-affected areas in the face of the approaching flood. Many buildings became uninhabitable due to lack of access, lack of safety and security, and lack of thermal comfort. Over the prolonged period of recovery these deficiencies became more pronounced. Residents were particularly put out by system failures that affected their wellbeing, comfort or safety. A building's lifts were identified as having the greatest impact on the liveability of multi-storey buildings as there are no mechanical substitutions available to provide the same service for tall buildings. The focus of the discussion was on the intersection between the architecture of the building and dependency on electrical systems that are increasingly being 'taken for granted' in contemporary Australian society.

This paper does not advocate for taller buildings as they have their own set of issues. More research is required to address the long-term implications of design choices that transpire as parties involved in



procuring such buildings make trade-offs based on their own criteria for project success. If urban consolidation policies are to be successful, the adaptive challenges of reducing greenhouse gas emissions must be addressed.

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